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# Lubrication

## A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

INBOARD MARINE ENGINES

PUBLISHED BY
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TEXACO PETROLEUM PRODUCTS

# LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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# INBOARD MARINE ENGINES

**PERHAPS pleasure boating may be said to have originated two thousand or more years ago with the royal barges of the Egyptians and Romans. The history of boating may then be followed up to the era of the palatial steam yachts, or not-so-elaborate steam launches, of the late Nineteenth Century. During all of this time, boating was restricted to the relative few among the population who possessed enough slaves to power the oars or enough dollars to buy and operate the yachts.**

**The coordinated developments of the internal combustion engine and of petroleum fuels and lubricants have changed all this, however. Today in this country, boating is a major sport and major industry, through the good work of boat and engine builders who have placed the cost within the reach of millions instead of a few. This article is devoted to the lubrication and fueling of motor boat engines, in the interest of greater enjoyment in boating and its even more widespread development as a national sport.**

A LITTLE over ten years ago, there were only about 167,000 registered power boats on federal waters in the U. S. — today there are nearly 500,000 such craft, despite four years of war during which no pleasure boats could be built. This tremendous growth is indicative of the interest in boating, which has become a major sport and industry with possibilities many times greater than the present level.

Federal waters are only those which connect with the sea, and registration is required only for boats powered with inboard engines. Thus, statistics do not include craft on inland lakes and sailboats or boats powered with outboard motors, which increase the total number of boats to something like 2,000,000 at present. With such numbers of boats in use, boating is not only a sport, it is big business.

Through the waterways systems in this country and the surrounding coastal waters, cruising possibilities in small motorboats are practically unlimited. The cost to the small boat owner is not high, since cruising runs are usually short and living and eating are done aboard. The increasing popularity of cruising on the network of inland and coastal waterways may be judged from the fact that one "Waterways Service" operated as a service to boat owners has answered over 250,000 inquiries about waterways since its beginning in 1933.

The operation of such a service is just one of the ways in which the petroleum industry has contributed to the development of boating as a sport and as an industry. Modern motor boating, which owes its existence to the development of reliable, high output internal combustion engines, is based as well upon the development of petroleum fuels and lubricants. These may truly be said to put the "pleasure" in "pleasure boating". Through outlets on all of America's waterways, the petroleum products which do this are available everywhere for the convenience of the boating public.

In the interests of improved operation with resultant greater pleasure and safety from boating, this article is devoted to a study of inboard marine engines, both gasoline and Diesel. Effective lubrication and selection of the most desirable lubricants and fuels

are vital considerations in this respect; and these are the subjects with which the article is largely concerned.

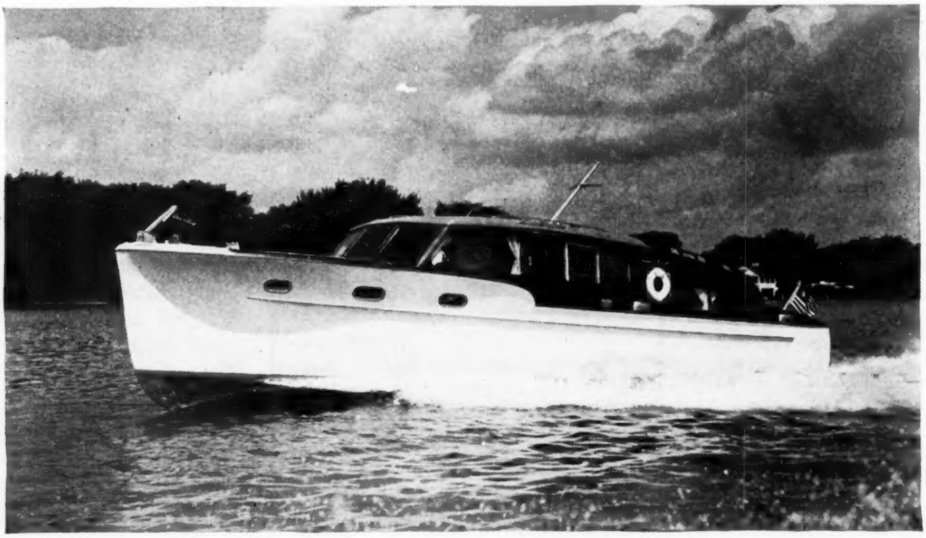
## Types of Inboard Marine Engines

Inboard marine engines may be classified in two general groups, according to the type of fuel, and correspondingly, the ignition means used. These types are gasoline engines, which operate with spark ignition on the Otto, or modified Otto, cycle; and Diesel engines, using compression ignition and the Diesel cycle.

Marine engines in these two classifications may be further sub-divided according to the number of piston strokes required to complete each combustion cycle; that is, whether two-stroke or four-stroke cycle is employed. Further subdivisions are possible in terms of cylinder or crankshaft arrangement. Other generic divisions may be made according to the type of cooling, or, as is customary in Diesel engines, according to the operating speed range. These divisions or subdivisions into various types of engines are shown in Fig. 2, which represents a sort of "Family Tree of Marine Engines."

Many other divisions as to type of engine or details of construction are possible, such as distinctions as to cylinder head and valve design, viz., L-Head or overhead valve, or distinction as to cylinder block construction. While these differences may be relatively important in matters such as engine life, reliability, and proper maintenance procedures, most types of engines share more or less common features concerning fuels and lubricants. Specific exceptions due to features of engine design or construction will be noted in the discussions that follow.

In general, the most popular types of inboard marine engines, both gasoline and Diesel, are based upon the in-line vertical arrangement, with 1 to 8 cylinders. The second most popular type is the V engine, of 2 to 12 cylinders. A third type is the in-line horizontal, which offers advantages in low head room required for installation.



*Courtesy of Chris-Craft Corporation*

**Figure 1—Enjoyment of power boating is mutually dependent upon the internal combustion engine and the petroleum products necessary for engine operation.**

## MARINE GASOLINE ENGINES

Most marine gasoline engines have a certain degree of general similarity to automotive gasoline engines, especially with regard to crankcase, cylinder, and piston construction. The similarity is likely to end here, however, since the intended use and operating conditions of marine engines dictate certain changes or modifications in manifolds, cooling systems, accessories, lubricating systems, and other parts. Marine carburetors are usually of the up-draft type, with upturned or angle air horns and non-drip features for safety. Flame arrestors are used instead of air cleaners. Ignition systems are similar to those used on automotive engines, taking into account the fact that the marine engine is more nearly a constant speed engine, and is not subject to the continual wide fluctuations in speed occurring in automotive use.

This latter point is due to propeller load, which is definite for any given rpm with a given hull

# CLASSIFICATION OF INBOARD MARINE ENGINES

## BOTH HIGH AND LOW SPEED INTERNAL COMBUSTION ENGINES FOR PLEASURE BOATS AND OTHER SMALL CRAFT

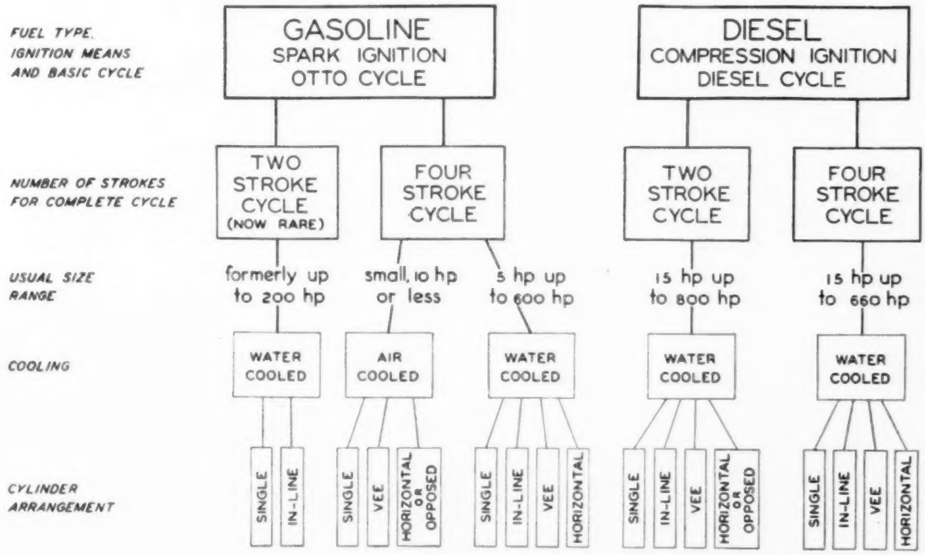



Figure 2—"Family Tree of Inboard Marine Engines".

and propeller. Such is shown graphically in Fig. 3, which represents full throttle brake horsepower (bhp) for a typical marine engine as compared to propeller horsepower required versus rpm.

From these curves, it is seen that in direct drive marine operation there is no such condition as full throttle, low rpm operation (except briefly while accelerating) or part throttle, high rpm operation, both of which are common in automotive service. On the other hand, the marine engine normally operates most of the time at a constant rpm, representing cruising power which may be 60% or more of the maximum power which can be obtained from the engine as fitted to the propeller and boat in question. As it has been aptly expressed in the past, "The motor boat engine constantly runs up-hill." It should be borne in mind, though, that this up-hill operation is not low-speed, full throttle lugging, but corresponds more nearly to climbing a constant slight grade at relatively high engine speed and load. With a reduction gear fitted to the marine engine, the automotive comparison might be made with a loaded vehicle pulling a steep grade in second gear at high engine speed.

Such operation as this necessarily constitutes heavy duty service. Although the engine for a particular installation, whether runabout, cruiser, auxiliary, or work boat, has been carefully selected to provide adequate power, still the requirement of continuous operation at relatively high engine speeds and power when underway imposes loads upon all mechanical parts approaching maximum design loads.

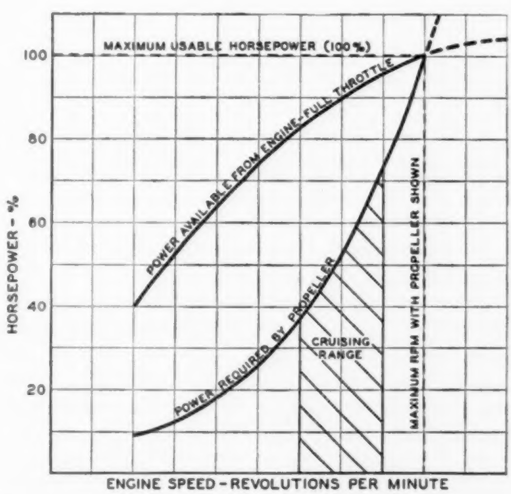



Figure 3—Engine horsepower available and propeller horsepower required versus r.p.m. for a typical engine and propeller combination.

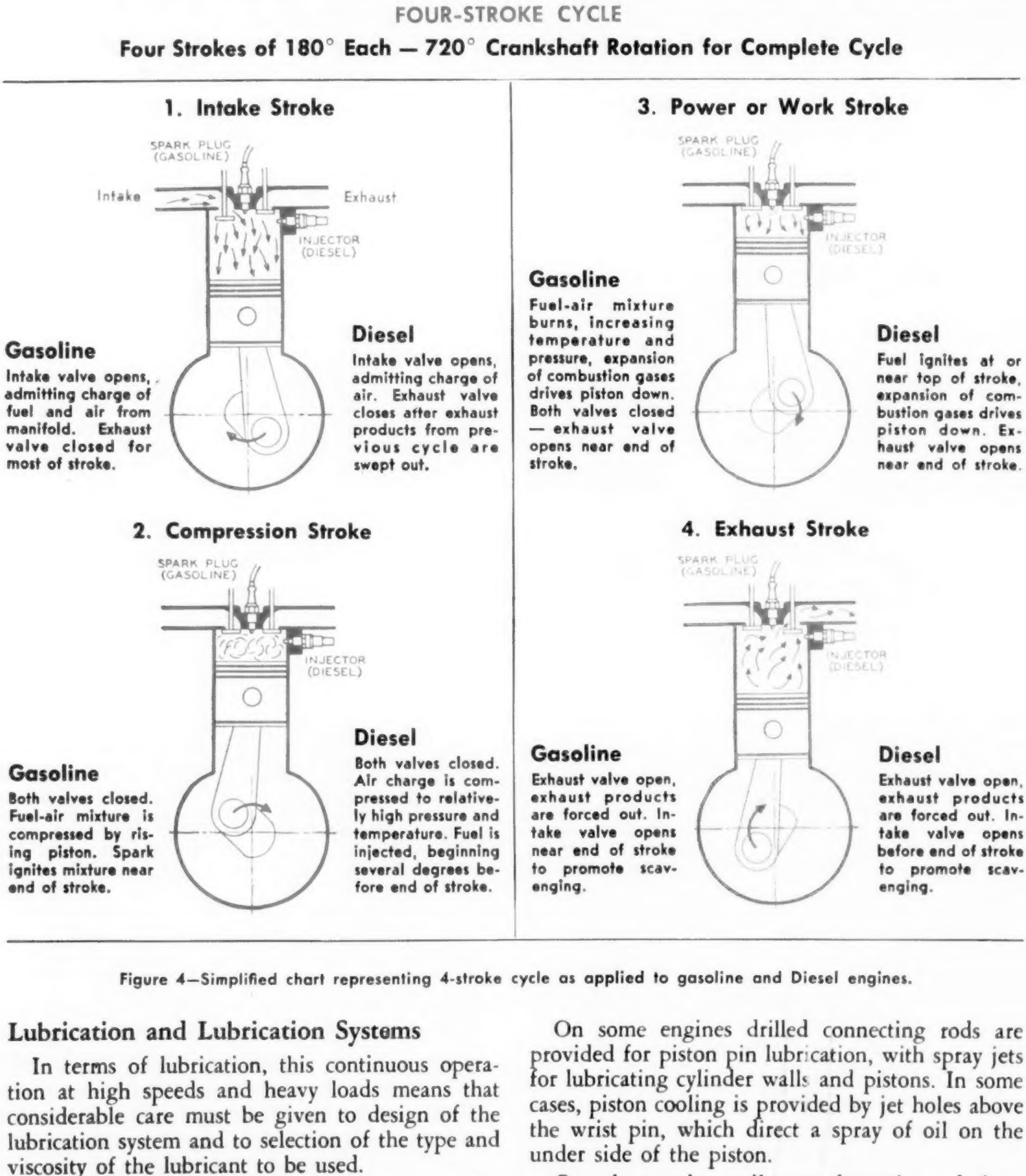



Figure 4—Simplified chart representing 4-stroke cycle as applied to gasoline and Diesel engines.

## Lubrication and Lubrication Systems

In terms of lubrication, this continuous operation at high speeds and heavy loads means that considerable care must be given to design of the lubrication system and to selection of the type and viscosity of the lubricant to be used.

Most marine engines employ full pressure lubricating systems which supply adequate quantities of oil under pressure to all necessary moving parts within the engine proper. Diagrams illustrating the lubrication systems of various engines are shown herewith. These have certain general features in common, in that the oil is taken from the crankcase or oil base by an oil pump driven by gears from the engine, and is pumped through oil lines or drilled passages in the block and shafts to all main, connecting rod, and camshaft bearings.

On some engines drilled connecting rods are provided for piston pin lubrication, with spray jets for lubricating cylinder walls and pistons. In some cases, piston cooling is provided by jet holes above the wrist pin, which direct a spray of oil on the under side of the piston.

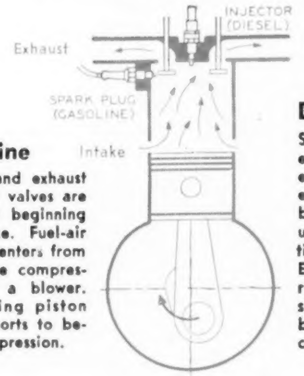
On other engines, oil spray from the end clearances around connecting rod and main bearings lubricates the wrist pins, pistons, cylinder walls, and other moving parts. With either system, oil which has passed through the pressure system and that which drains from the push rod chambers and from lower cylinder walls, etc., drains back into the crankcase sump.

Oil filters may be of either the full flow or by-pass type. In the latter only a portion of the oil from the pump passes through the filter, but

## TWO-STROKE CYCLE

**Two Strokes of 180° Each — 360° Crankshaft Rotation for Complete Cycle**

### 1. Upward Stroke — Intake-Exhaust



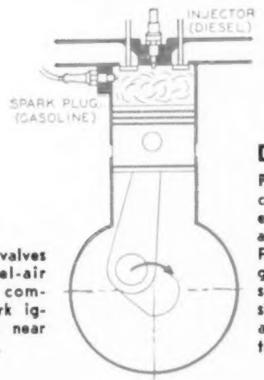

**Gasoline**

Intake and exhaust ports or valves are open at beginning of stroke. Fuel-air mixture enters from crankcase compression or a blower. Ascending piston closes ports to begin compression.

**Diesel**

Same as gasoline, except that only air enters cylinder. An externally driven blower is generally used to assist induction and scavenging. Exhaust ports may remain open later since only air will be lost from new charge.

### 2. Compression



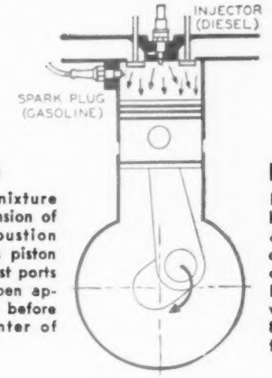

**Gasoline**

Ports and/or valves closed. Fuel-air mixture is compressed. Spark ignites mixture near end of stroke.

**Diesel**

Ports closed. Air charge is compressed, raising pressure and temperature. Fuel injection begins approx. 10° or so before top of stroke, usually ends at or just before top center.

### 3. Downward Stroke — Power



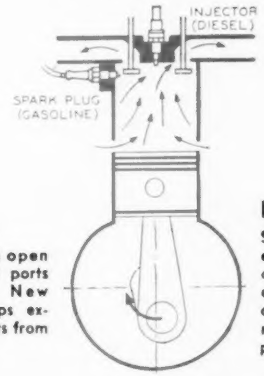

**Gasoline**

Fuel-air mixture burns, expansion of hot combustion gases drives piston down. Exhaust ports or valves open approx. 80-90° before bottom center of stroke.

**Diesel**

Fuel ignites and burns with charge air, expansion of combustion gases drives piston down. Exhaust ports or valves open approx. 80-90° before bottom center.

### 4. Exhaust-Intake




**Gasoline**

Intake ports open after exhaust ports or valves. New charge sweeps exhaust products from cylinder.

**Diesel**

Same as gasoline, except that new charge consists only of air. Intake ports can open earlier if required for complete scavenging.

Figure 5—Simplified chart representing 2-stroke cycle as applied to gasoline and Diesel engines.

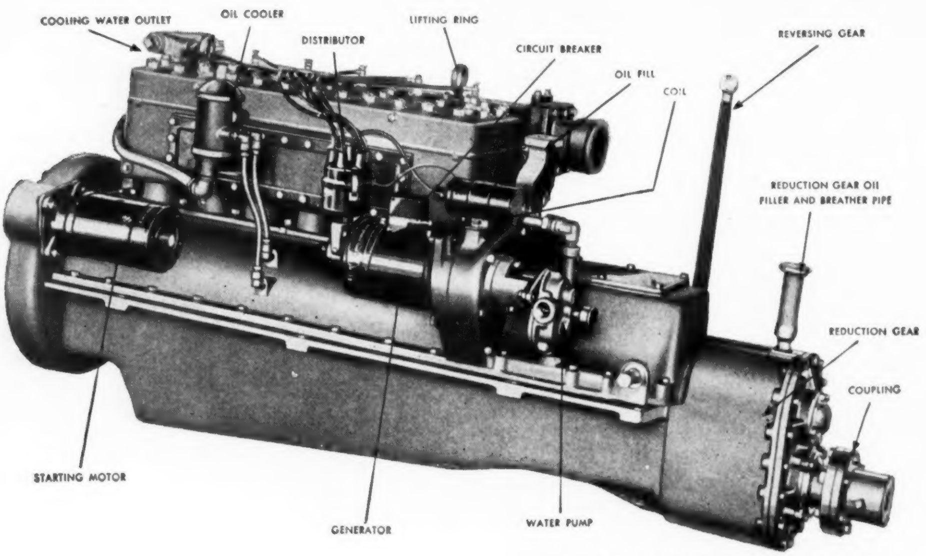
through continuous circulation, the bulk of the oil is filtered.

Since there is no provision for air flow around the crankcase oil pan or sump, as there is in highway vehicles, in many marine installations provision of an oil cooler is important. In other cases, where the oil would not reach excessive temperatures even at continuous full power operation without a cooler, the use of a cooler may not be necessary, since maintenance of a reasonable oil temperature of 160°F. is required for proper operating viscosity and to prevent condensation of moisture and blow-by gases in the crankcase to retard the formation of sludge and engine deposits.

Maintenance of the crankcase oil temperature below a maximum of 210-220°F. is also desirable for prevention of oil oxidation, and sludge which may form from oxidation products. Necessity for keeping the oil temperature up is further emphasized by the fact that marine installations tend to be over-cooled with respect to engine block and jacket temperatures, with the attendant possibilities of increased wear and low temperature sludge formation in the crankcase. This leads to a review of cooling practices and the influence of jacket water temperature on operation, which is discussed in the following section.

### *Influence of Jacket Water Temperature*

Cooling of inboard marine engines is most commonly accomplished by pumping sea water through the cylinder block jackets and passages. The water is piped to a cooling jacket surrounding the exhaust manifold either before or after going through




*Courtesy of Universal Motor Company*

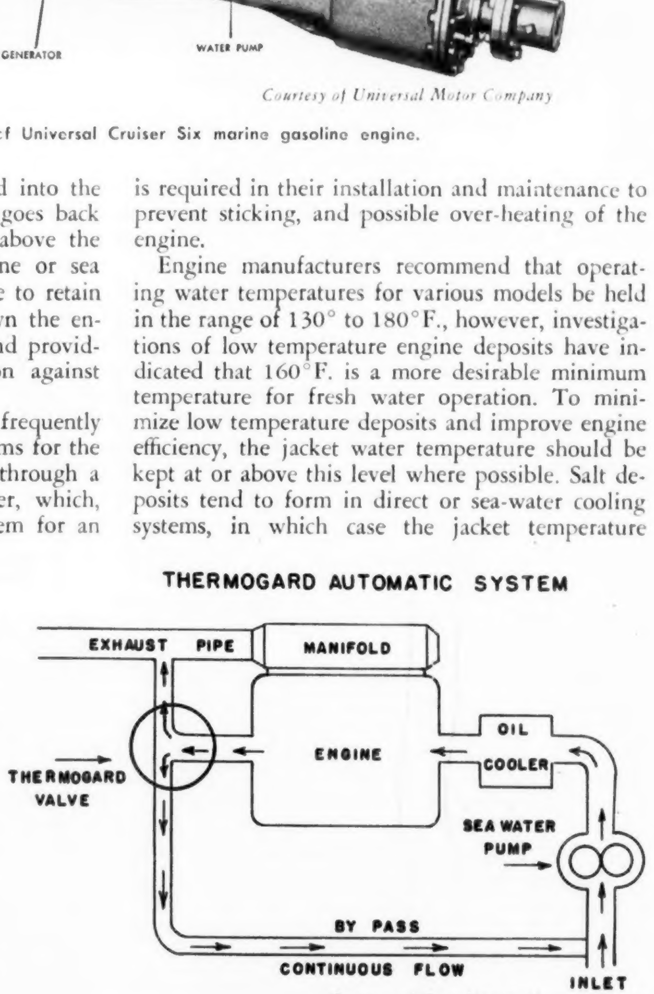
Figure 6—Port view of Universal Cruiser Six marine gasoline engine.

the engine jacket and is finally emptied into the engine exhaust pipe, through which it goes back into the sea. If the engine is located above the water line, the water pump suction line or sea cock should be fitted with a check valve to retain water in the jackets when shutting down the engine, thus preventing loss of priming and providing for gradual cooling and protection against corrosion.

Larger boats operating in salt water frequently use enclosed or fresh water cooling systems for the engine. In these, sea water is pumped through a heat exchanger to cool the jacket water, which, barring leaks, may be kept in the system for an entire season. Two pumps are ordinarily required for such an installation, one for the enclosed system and one for the sea water system. Some boats use heat exchangers on the side of the hull, eliminating the second pump. Where sufficient space is available, and the cost is warranted for a fresh water system, corrosion of the engine cooling jackets and the rest of the enclosed system may be practically eliminated if proper practices are followed in laying up.

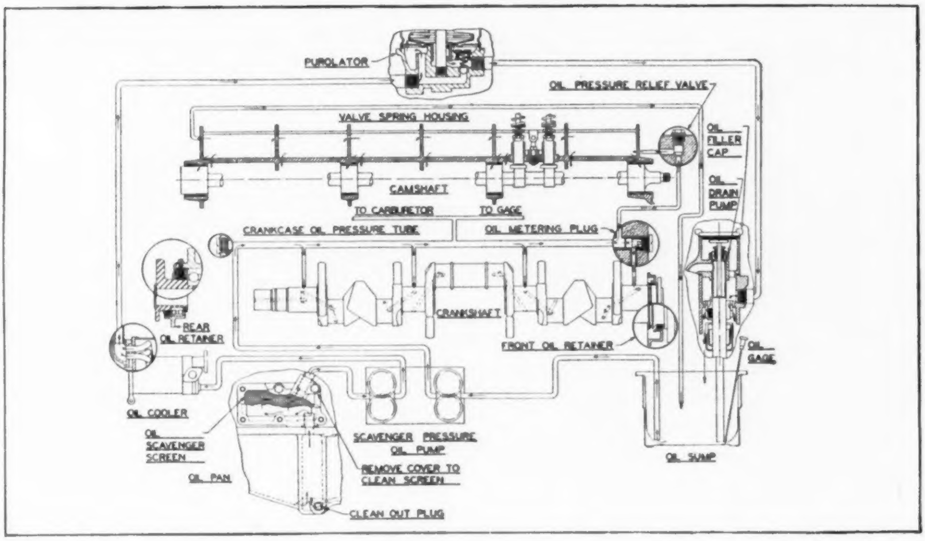
Both direct sea water and enclosed, or indirect, systems may incorporate thermostats, which are usually located on the engine cooling water outlet and by-pass water to the pump suction side when water temperatures are below the desired level. Where thermostats are used to control water temperature, care is required in their installation and maintenance to prevent sticking, and possible over-heating of the engine.

Engine manufacturers recommend that operating water temperatures for various models be held in the range of 130° to 180°F., however, investigations of low temperature engine deposits have indicated that 160°F. is a more desirable minimum temperature for fresh water operation. To minimize low temperature deposits and improve engine efficiency, the jacket water temperature should be kept at or above this level where possible. Salt deposits tend to form in direct or sea-water cooling systems, in which case the jacket temperature




*Courtesy of Gray Marine Motor Company*

Figure 7—"Thermogard" automatic cooling system used on Graymarine motors.




*Courtesy of Scripps Motor Company*

**Figure 8—Lubrication system of Scripps motors, Models 162, 172A, 202, others.**

should not exceed 145-150°F. to prevent excessive deposits and scale.

The results of operation with excessively low jacket water temperatures are incomplete combustion, with greater amounts of fuel soot, intermediate combustion products, or raw fuel washing past the rings; and condensation of moisture on crankcase or cylinder walls, resulting in contamination of the lubricating oil, as well as increased wear and tendency to corrosion. The products of combustion and water in the lubricating oil may combine to form so-called low temperature sludge and engine deposits. The effect of excessively low jacket water temperature may also show up as valve spring breakage, caused by corrosion through condensation in valve chambers.

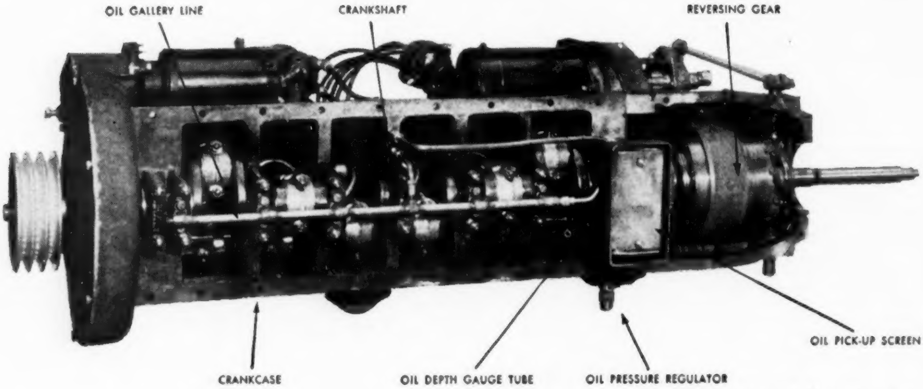
## Selection of Lubricants

The truly heavy duty service to which marine gasoline engines are subjected calls for the use of a heavy duty oil for best operation and maximum engine life. During the past several years, rapid gains have been made in the development of heavy duty motor oils, largely through incorporation of carefully selected additives which fortify the properties of the most desirable type of highly refined base oils. As a result, marine motor oils are available today with the desired heavy duty characteristics, offering the following advantages over other types of lubricants:

1. Detergency-dispersion properties, which keep engines cleaner.
2. Anti-oxidation properties, which, coupled with detergency-dispersion, keep piston rings free, assuring full power and lower maintenance costs.
3. Anti-sludging action, from the combined action of the above properties, plus improved demulsibility.
4. Protection against corrosion of marine engine bearing materials.
5. Anti-rust protection during idle or lay-up periods.
6. Higher film strength, giving extreme pressure and anti-wear properties which improve gear lubrication and also breaking-in of new engines.

Because of the high speeds and loads at which they operate, marine engines often use a somewhat more viscous grade of oil than would be used in automotive engines at the same temperatures. On the other extreme, too heavy an oil should be avoided to eliminate excessive internal friction or hard starting. Information is readily available from engine manufacturers and from marine service stations as to the correct viscosity grade to be used in various makes and models of engines for any given temperature. For best results in engine lubrication, these instructions should always be followed.

Often there is a tendency to attempt to offset high oil consumption resulting from worn rings, cylinders, or bearings by using a heavier grade of oil. While this may be effective to some degree temporarily, it cannot be a substitute for overhauling the engine, and in many cases, may be detrimental in producing further wear through insufficient oil supply. In any event, power lost due to poor compression from worn rings or excessive clearances cannot be regained short of re-condition-




*Courtesy of Universal Motor Company*

**Figure 9—Bottom view of Universal Cruiser Six marine engine, with oil base removed, showing oil gallery lines and other parts of oil system.**

ing the engine; and it is inadvisable, if not foolhardy, to risk having to rebore or junk a basically good engine in order to avoid timely replacement of rings or of one or two time-worn bearings.

## Marine Gasolines

Marine gasolines, upon which satisfactory and efficient operation of motor boats depend, have been much discussed, and sometimes even "cussed", during the history of pleasure boating. Much of this discussion would have been unnecessary, however, if a mutual understanding of the properties and characteristics of engines, fuel systems, and fuels, and their inter-relationships, had been available to manufacturers, owners, and refiners.

The important characteristics of marine gasoline which concern the boat operator are:

1. Octane, or anti-knock rating.

2. Volatility, or evaporation tendencies.

3. Stability, or resistance to gum and deposit formation.

### *Octane Rating*

Operating at high loads a large percentage of the time and often at or near full throttle, marine gasoline engines require a fuel of adequate octane rating in order to attain best performance and efficiency. Octane rating is a measure of the resistance of the fuel to knocking, which is defined as sudden or instantaneous burning of the last part of the fuel-air charge after the spark has fired and has ignited a normal flame in the combustion chamber. (See illustrations, pages 84 and 85.)

Interference of the normal burning characteristics by knocking due to low octane fuel results in loss of power and efficiency due to the sudden and inefficient pressure fluctuations of the knocking combustion, in place of the smooth pressure that is desired. Moreover, gas temperatures and combustion chamber and piston temperatures are sharply increased by knocking, with attendant possibilities of engine overheating and damage.

As set up for best operation, excluding the effects of carburetion as discussed later, each model of marine engine will have a minimum octane requirement or required level of fuel anti-knock quality. This octane requirement is a function of many variables, including compression ratio, spark advance, rpm, and inlet manifold temperature. Other features such as combustion chamber design, spark plug and valve location, or location of cooling water passages also exert a major effect on octane requirement, but are beyond the control of the boat owner; therefore the so-called operating variables are more significant to this discussion.

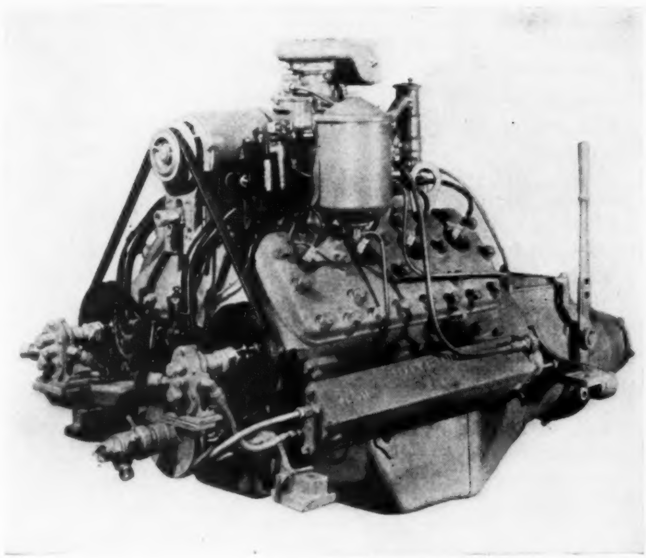
Of these variables, spark advance is the only one besides throttle setting that can be conveniently adjusted for control of knocking. With other variables fixed at the desired or existing operating levels, a rather large amount of spark advance is ordinarily required for optimum combustion. Increasing spark advance increases octane requirement, however. Thus, when it is necessary to operate marine engines on gasoline of lower octane than the engine requires at optimum conditions, it is customary to retard the spark setting sufficiently to eliminate knocking, which results in a loss of power and efficiency from that obtained with the optimum spark advance.

Spark timing should not be advanced beyond the point of maximum power, however, since greater advance results only in power loss and an unnecessary increase in octane requirement without a net gain in any form. For this reason, when using fuel of higher octane than that required by the engine, the spark should not be advanced until light knocking is obtained, which is sometimes done. Instead,

the procedure given on Page 91 is recommended for setting the timing, using the advance for best power, but no more, when fuel octane permits.

Modern marine engines generally have octane requirements of from 72 to 78, when set for best performance and efficiency. Marine gasoline which will satisfy this octane requirement is now available. Significantly, the anti-knock quality is obtained without the use of tetra-ethyl lead, through utilization of high-octane refining processes developed for aviation gasoline just before and during the recent war.

Some pre-war types of straight-run marine white gasolines did not have the high octane required, and were usable only with retarded spark settings. To get full power and lowest fuel consumption, a marine gasoline which will allow spark advance to be set for top performance without knocking should be used.



*Courtesy of Osco Motors Corporation*

**Figure 11—Osco Series 5-100 marine gasoline engine.**

### *Volatility*

The volatility of marine gasolines, or tendency to vaporize, controls engine performance through the effects of vapor pressure and the boiling range as follows:

1. Vapor pressure and the low boiling range affect vapor locking and ease of starting.
2. The low and mid-boiling ranges control warm-up and acceleration characteristics.
3. The higher boiling range affects mixture distribution, economy, and crankcase dilution.

The commercial measurements of gasoline vapor pressure and boiling range are made by means of Reid Vapor Pressure and ASTM Distillation, respectively. Reid Vapor Pressure (RVP) is determined in a test bomb, in which a gasoline sample is pre-chilled and then submerged in a water bath at 100°F. An air chamber and pressure gage are attached to the gasoline chamber of the bomb, and the fuel vapor pressure at the 100°F. temperature is read directly on the gage after allowing for the pressure of the air also in the bomb.

The ASTM Distillation is determined by evaporating the gasoline in a flask at a standard rate and noting the temperature at which successive increments of fuel are condensed. Results are plotted on a curve such as that in Fig. 10. Notes on the curve indicate the significance of various portions in terms of effect on engine operation.

The vapor pressure and low boiling range temperatures selected for marine gasoline must be a compromise between (1) high vapor pressures and low distillation temperatures which promote cold starting and (2) lowered vapor pressure for prevention of vapor lock. Since motor boats cannot be operated at very low temperatures, much below freezing; but, on the other hand temperatures in the engine compartment and of fuel lines, pump, and carburetor may be quite high in summer, a low vapor pressure is selected for freedom from vapor locking. The resultant initial and 10% boiling points provide adequate starting, even when boats are used in late fall or winter.

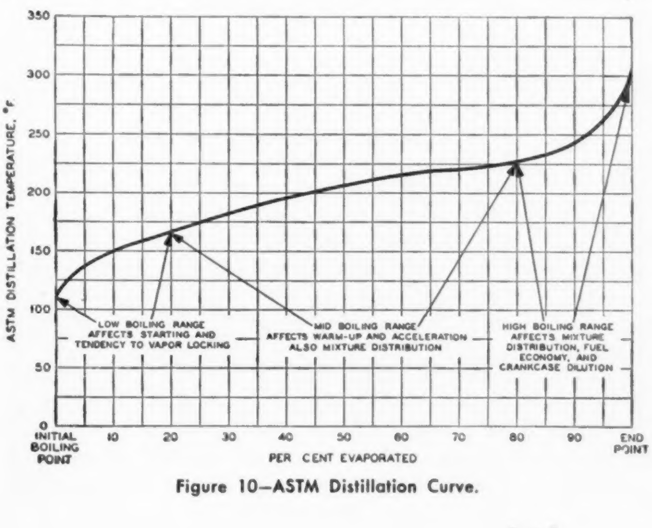
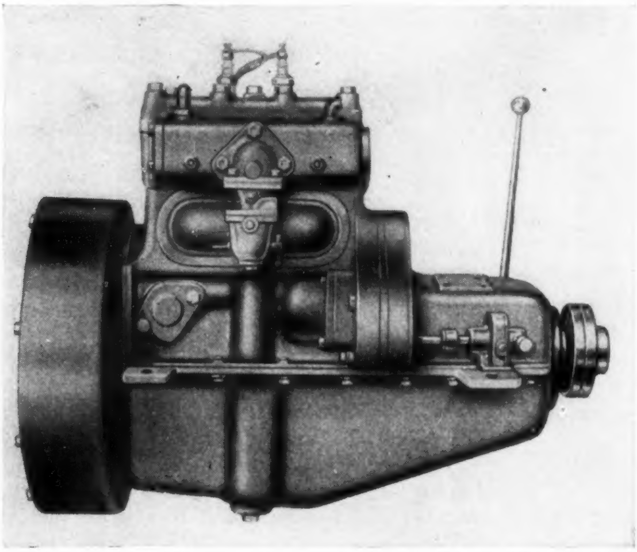



**Figure 10—ASTM Distillation Curve.**

Inasmuch as jacket water and inlet manifold temperature ordinarily tend to be on the low side in marine engines, low 50% and 90% distillation tem-

peratures are desirable for short warm-up and good acceleration or throttle response. It is difficult to pin exact numbers on the distillation temperatures required, in view of the large differences between various marine engines. However, knowledge gained from the development of aviation gasolines, which are subjected to even more severe conditions, has been used in developing a balanced distillation range for marine gasolines, affording the desired high performance.

With such a balanced distillation range, incorporating also low end or final boiling point temperatures, mixture distribution is improved, resulting in smoother, more flexible operation and greater fuel economy. Freedom from crankcase dilution results from the low temperatures in the fuel's high boiling range, if engines are in good mechanical condition with proper carburetion and reasonably high jacket temperatures.



*Courtesy of United States Motors Corp.*

**Figure 12—United States Motors Model BX3M medium speed 10 h.p. marine gasoline engine.**

### *Stability*

The greatest need for stability, or resistance to gum formation, in marine gasolines results from the use of copper in fuel tanks, lines, and other portions of motor boat fuel systems. The use of copper is of long standing, and in part results from the fact that the resistance of copper to salt-water corrosion was discovered and well known before it was equally as well known that copper is an active catalyst in promoting oxidation or formation of gum and varnish from gasoline. For such is the case, and although other tank and fuel system materials suitable for use in salt water conditions are now available and in use, the traditional use of copper continues. Rightly or wrongly so, it is then up to fuel refiners and marketers to provide marine gasolines which will resist the catalytic action of copper and remain stable and gum-free when left in contact with copper and air for long periods.

Traditionally, gum resistant marine gasolines have been entirely straight run products, distilled directly from crude oil. All straight run gasolines are not of the same type and, in fact, large differences in gum resistance may exist. The mere fact that a gasoline is produced by a straight run process or is unleaded will not ensure freedom from gum. Then, too, a wholly straight run fuel without lead is likely to have too low an octane number for best marine use. Thermally cracked gasolines and also catalytically cracked products have higher octane, but are usually unsuitable for use with copper tanks due to their relative instability to gum formation.

The greatest gum resistance, amounting to practical freedom from troublesome types of gum even after long storage in the presence of copper and air, is found in straight run gasoline from selected crudes and in certain synthetic high octane products now available. A blend of these components, judiciously selected, comprises a truly premium marine white gasoline, in that the requirements of octane and volatility are also satisfied. Tests show no significant formation of gum in such a fuel after six months storage in copper tanks with air present at summer temperatures.

Gum is formed when gasoline combines with oxygen from dissolved or adjacent air and the resultant compounds polymerize, or form larger molecules. The formation of gum is usually accelerated by exposure of the gasoline to copper, which acts as a catalyst. Thus a large portion of gum troubles would be prevented by the use of tin-lining in copper fuel tanks, or by the use of stainless, galvanized, or Monel for tanks and fuel system parts. When copper is used, marine gasoline of high stability, as discussed above, will prevent severe or drastic gum formation, although it is still wise to avoid leaving gasoline in the tanks when boats are laid up.

### *Carburetion and Spark Setting*

Both efficiency and power of a gasoline engine depend vitally upon carburetion, or the proportions

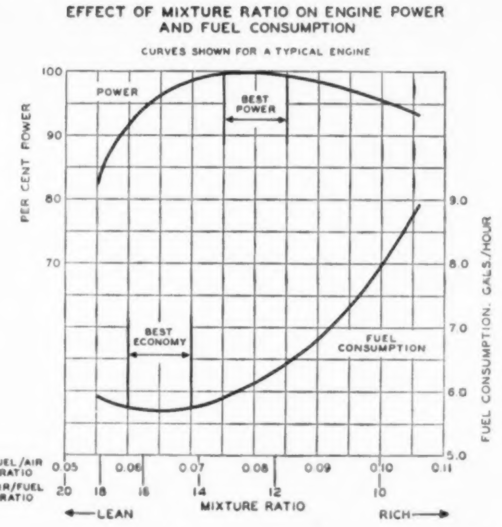



Figure 13—Effect of mixture ratio on engine power and fuel consumption for a typical engine.

in which the fuel is mixed with the intake air by the engine carburetor. In general, carburetors are reliable and trouble-free, barring clogging from dirty fuel or mis-treatment. Once established, proper mixture settings usually may be relied upon to last for several years, so that the carburetor generally should be the last item disturbed in trouble shooting or engine adjustment under ordinary circumstances.

To attain the most desirable operation, however, the initial carburetor setting should be properly made. In order to make proper settings, a brief review of the effect of carburetion, or mixture ratio, on engine operation will be helpful.

At constant throttle setting and rpm, the effect of mixture ratio on power and fuel consumption for a typical engine is shown in Fig. 13. The best power and best economy zones do not coincide, and for this reason, it is customary to make normal carburetor setting in between this range. For continuous cruising, or for racing, though, settings on the best economy or best power side, respectively, might be preferred. For most purposes a cruising setting in the best economy range will generally suffice, since most carburetors automatically enrich the mixture at full throttle, placing the resultant mixture at such conditions near that for best power.

Engine manuals and other references provide instructions for making carburetor adjustments, and it is recommended that they be followed carefully. Extremely lean mixtures should be avoided, inasmuch as they tend to cause overheating and valve burning, as well as tendency toward knocking, and therefore, increased octane requirements. Likewise, excessively rich mixtures waste fuel and may foul spark plugs and create crankcase dilution. It is well to emphasize that once the proper adjustment is made, there is very little that can go wrong with the carburetor—tinkering is not advisable.

With proper carburetor setting, obtaining full power from a marine engine in good mechanical order then becomes a matter of ignition timing. The effect of ignition timing, or spark setting, on power for a typical engine is shown in Fig. 14. Adjustment of spark timing may be made with most engines by rotation of the distributor body.

There are two simple methods of checking and setting ignition timing, both of which should be used whenever the distributor has been removed and replaced or when tuning up the engine: First, static setting, and second, setting with engine running at full load. Instructions for checking the static setting are given in most engine manuals or can be made by a mechanic familiar with the make of engine.

The second and final check should be made with the engine operating at full throttle, thoroughly warmed-up, and the boat under-way. Most distributors have a clamp at the base which permits adjustment of the distributor body and, consequently, the timing. The timing should be advanced beyond the point of maximum rpm until the engine speed begins to drop off, then retarded back past maximum until speed again falls off. Best power and efficiency are obtained at the point of maximum rpm, and the final setting should be made as near this point as possible.

If knocking is encountered at or before the spark advance for best power, the spark should be retarded just enough to eliminate the knock at full throttle. The better type of marine gasoline will permit advancing the spark to the best power setting, thus assuring maximum power output and fuel economy from the engine.

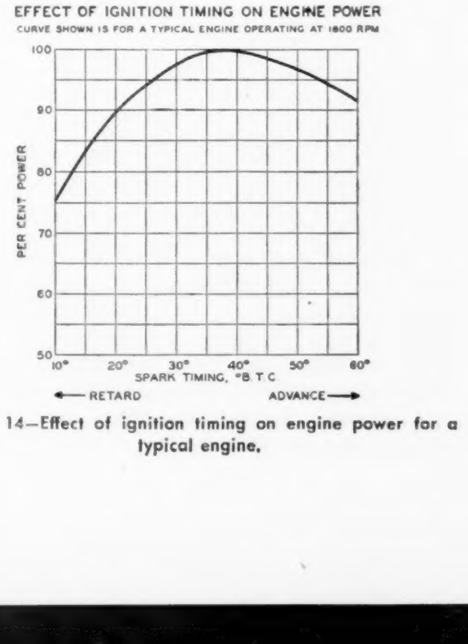
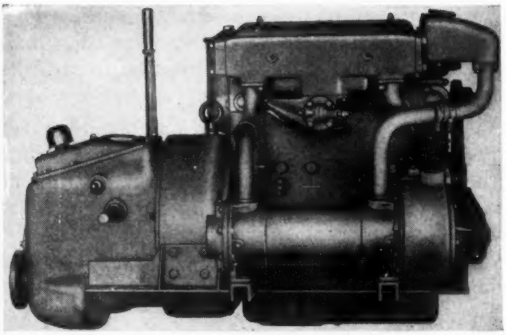



Figure 14—Effect of ignition timing on engine power for a typical engine.



*Courtesy of Gray Marine Motor Company*

**Figure 15—Exterior of Graymarine four-stroke cycle marine Diesel engine.**

## MARINE DIESEL ENGINES

For small craft powered by Diesel engines, the high-speed, automotive type of engine is generally used, rather than the larger-bore, slow speed type. The latter are sometimes fitted in workboats, where their durability and extreme fuel economy are prime considerations; however, the discussion here will be confined to the types of medium and high-speed Diesel engines most widely installed in pleasure boats and other small craft.

For such, the in-line, water-cooled arrangement has been adopted practically without exception. The horsepower output for these engines ranges from 15 up to several hundred, with engines in the 40 to 200 h.p. classification the most popular sizes for pleasure boat installations. Large cruisers and power yachts often use two or more Diesel engines, of 150 to 200 h.p., to drive twin screws.

In the operating cycle, the Diesel engine differs from the gasoline engine in that air alone is drawn or blown into the cylinder on the intake stroke (Figs. 4 and 5). Toward the latter part of the compression stroke, which is carried out to relatively higher temperatures and pressures due to the use of much higher compression ratio, fuel is injected into the cylinder through a high pressure nozzle. The fuel injection system may incorporate an integral high pressure pump and nozzle unit or may have a separate engine driven high pressure pump which supplies a metered quantity of fuel to the injector on each cylinder.

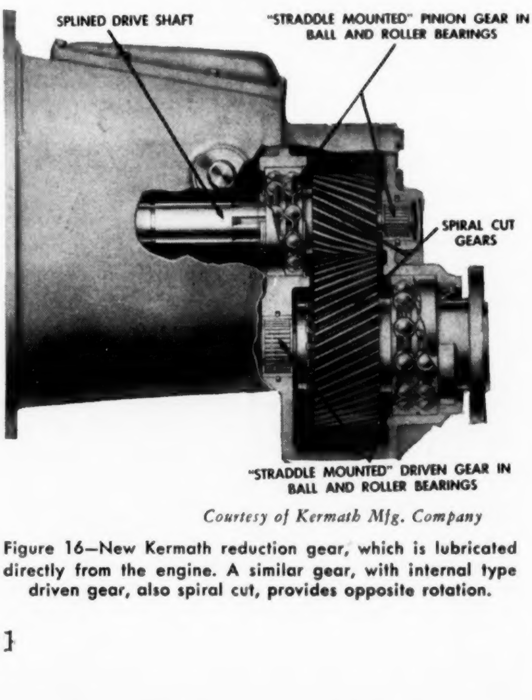
Both 4-stroke cycle and 2-stroke cycle are used in marine Diesel engines. Engines operating on the 2-stroke cycle use an air blower, or supercharger, to supply air during the late exhaust-intake part of the cycle, the pressure of the air aiding in sweeping out or "scavenging" the exhaust gases. The air is usually admitted through a ring of intake ports in the lower cylinder wall, and the exhaust ports may be similar, or as is more common, conventional poppet exhaust valves may be used.

With marine Diesel engines, as with gasoline engines, propeller load also fixes the horsepower required at any rpm. Instead of using a conventional throttle on the air intake, however, power and speed are controlled by the amount of fuel injected into the cylinders, which is increased up to the point of maximum power or full load. This results in greater part load economy, which is significant in long range cruising.

### Lubrication and Lubrication Systems

The internal lubrication system of high speed inboard marine Diesel engines is usually of the fully pressurized type. Oil is supplied from an engine driven pump to main distribution passages, or oil galleries, located along the engine block. From these, the oil is distributed to the main bearings, to vertical passages which feed to camshaft end bearings, and to overhead passages which in turn supply rocker arm shafts and bearings and other lubricated parts of the overhead cylinder mechanism. Oil for the lubrication of connecting rod bearings and piston pins is provided from the main bearings through drilled passages in the crankshaft. Oil cooling of the underside of the piston is usually employed, through spray jets on top of the connecting rods which are fed from the piston pin bearing oil supply.

Gear trains are lubricated by overflow of oil from the camshaft and overhead supply systems. Excess oil from the rocker arms lubricates the valve and push rod ends and generally is drained



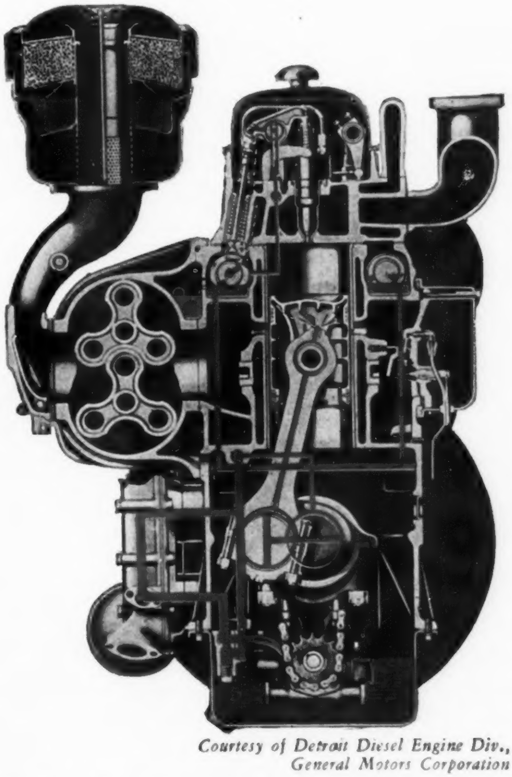

*Courtesy of Kermath Mfg. Company*

**Figure 16—New Kermath reduction gear, which is lubricated directly from the engine. A similar gear, with internal type driven gear, also spiral cut, provides opposite rotation.**

back through gear housings, from which it returns to the oil pan or sump.

The external system, which is supplied from the oil pan on all except the largest engines, normally consists of an oil pump, a strainer, a filter, and an oil cooler. A pressure relief valve is provided at the pressure pump, with a by-pass relief valve around the strainer and cooler to ensure positive oil supply.

The influence of oil temperature on high speed Diesel operation is important and must be taken into account for best engine operation.



*Courtesy of Detroit Diesel Engine Div., General Motors Corporation*

**Figure 17—End cross-section of General Motors Series 71 two-cycle Diesel engine, showing lubrication diagram.**

On one hand, high crankcase oil temperatures are desirable in order to obtain decreased frictional resistance due to the viscosity or drag of the oil in bearings and on other moving parts. High crankcase temperatures also prevent condensation of moisture in the crankcase and help drive off any dilution from unburned fuel that might wash past the rings. A third benefit is obtained in the form of greater filter efficiency at higher oil temperatures.

On the other hand, excessively high oil temperatures promote oxidation of the oil, forming sludge and other products which may tend to be corrosive to bearing metals. The strength and fatigue resistance of bearing metals is also decreased at elevated temperatures, which limits the desirable temperature on the high side.

Sludge and engine deposits may form on either end of the crankcase temperature scale. With heavy duty oils (discussed below) the high temperature limit may be somewhere around 250°F. or slightly higher, while the low temperature limit is at least 160°F. for best operation.

With fresh water cooling systems, oil and jacket water temperatures should run about the same. Tests have shown the desirability of maintaining both at approx. 180°F. for best results. Since sea water or direct cooling systems are subject to salt deposits at this temperature, it may be desirable to reduce the jacket temperature somewhat with these installations. The crankcase oil temperature may then be maintained at a higher level by controlling the amount of cooling water which passes through the oil cooler.

## Selection of Lubricants

The advent of the high speed Diesel engine introduced new problems in engine lubrication — problems which are not directly concerned with lubrication itself in the strictest technical sense. These problems were those of piston ring sticking or clogging and of excessive engine deposits. At the same time, the heavy duty usage of the high speed Diesel engine accentuated the need for better lubricants to eliminate piston and ring scuffing, wear, and bearing failures.

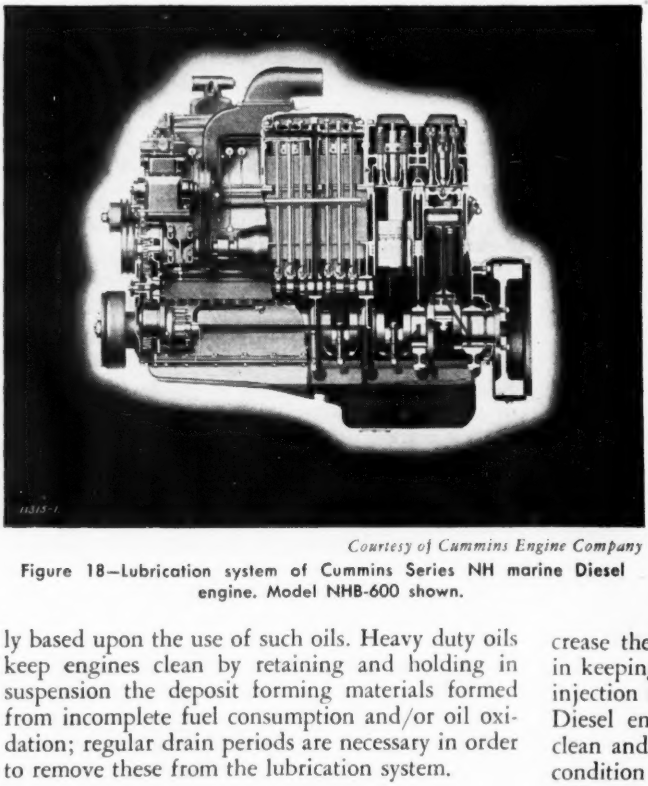
Two characteristics of the high speed Diesel come into play to bring about the tendency to ring sticking and deposits; namely, higher temperatures in the piston belt and greater contamination of lubricating oils with the products of fuel combustion, principally soot. To meet these conditions, the petroleum industry, with the cooperation of engine manufacturers, has developed heavy duty oils, which incorporate chemical additives to obtain the necessary properties. In high speed Diesel engines such as those used in motor boats, as in heavy duty gasoline engines, these oils provide the benefits listed on page 87.

While heavy duty oils in general possess these characteristics, it is not meant to imply that all heavy duty oils are alike in the degree of these properties they exhibit. Rather, the degree or amount of benefit that will be shown in service is a function of the amount and nature of the additives used, the properties of the base oils with which they are blended, and the combined properties which the blends exhibit. Heavy duty detergent type oils having a satisfactory performance history in the type of engines used are a "must" for marine

Diesel engines, if full service and enjoyment are to be obtained.

Oil viscosity grades should be determined from the manufacturers' recommendations. With respect to ease of starting, in particular, seasonal grade changes recommended by the engine manufacturer should be followed in cold weather operation.

Maximum oil change periods as recommended by the engine manufacturer should never be exceeded. Best results are obtained with drain intervals of 50 to 100 hours. While the use of heavy duty oils has permitted a general increase in the number of hours of operation between drains, present drain period recommendations are generally based upon the use of such oils. Heavy duty oils keep engines clean by retaining and holding in suspension the deposit forming materials formed from incomplete fuel consumption and/or oil oxidation; regular drain periods are necessary in order to remove these from the lubrication system.



*Courtesy of Cummins Engine Company*

**Figure 18—Lubrication system of Cummins Series NH marine Diesel engine. Model NHB-600 shown.**

## Marine Diesel Fuels

A wide range of Diesel fuels is available, varying from light kerosine type to heavy furnace oils. The lighter, more volatile fuels burn cleaner in the high speed Diesel, whereas the heavier grades have higher heat content per gallon, giving somewhat better fuel economy. Choice of fuel for the high speed engines used in inboard marine service is a compromise between the better fuel economy of the heavier fuels and the improved combustion afforded by the lighter fuels.

Fuels are commonly classified by Grade Numbers, such as 1, 2, 3, etc. The No. 1, 2, and 3 grades give best results in high speed Diesels; and most petroleum companies have such grades available at waterfront service stations.

The most important criteria of Diesel fuel quality are volatility, ignition quality, and cleanliness.

Volatility, or the vaporization tendency, is measured in terms of the boiling range. As stated above, lower boiling fuels burn more cleanly than do higher boiling fuels due to the relatively greater ease of evaporation.

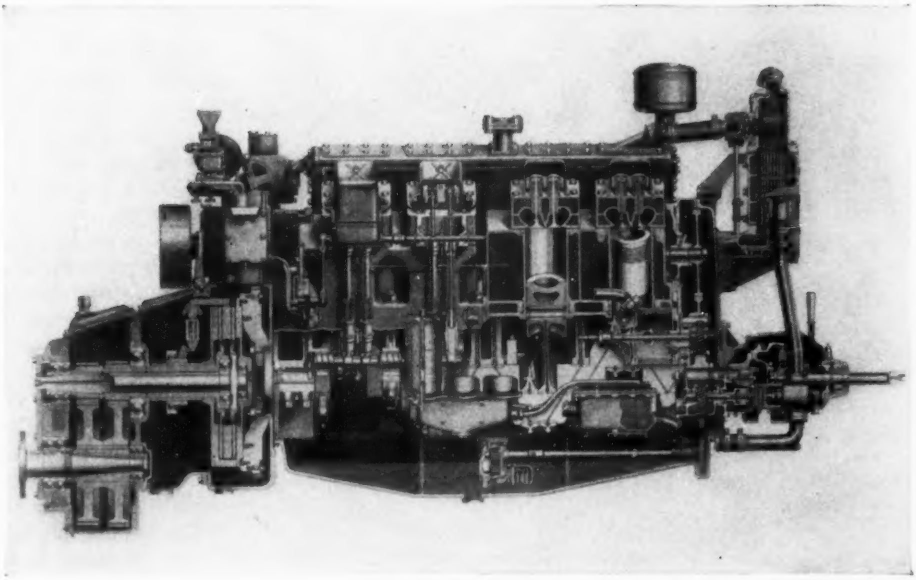
Ignition quality is expressed in terms of Cetane Number, which is a measure of the ignitability of fuel in a Diesel engine. Combustion knock in a Diesel engine is due to failure of the first part of the fuel charge to ignite spontaneously when it is injected into the cylinder, resulting in a delay period during which fuel is accumulated. When the fuel does ignite spontaneously, burning of the relatively larger amount results in a rapid pressure rise from which a knocking sound wave is originated. In addition to causing knocking, fuels of poor ignition quality may result in piston varnish formation when the engine is idling cold.

A clean, non-corrosive, non-gumming fuel is required for proper functioning and protection of the fuel injection system. The fuel also must have sufficient viscosity to lubricate the fuel pump plungers and injectors to prevent scoring and wear. Improper injection of the fuel results in soot deposits in the engine as well as in dilution of the crankcase oil.

### *Effect of Fuel Injection System*

Deposits from poor injection increase the burden imposed on the lubricating oil in keeping the engine clean. In many respects the injection system is the most important part of the Diesel engine, for upon its performance depend clean and efficient combustion of the fuel and the condition of the lubricating oil. Dilution of the oil will not occur if fuel is injected and burned properly.

Proper injection timing and pressure, the spray pattern, and dribbling after injection are factors that should be checked and controlled. Ordinarily these must be checked and adjustments made by an experienced mechanic; for those boat operators who have the facilities and ability to do their own work, the engine and injector instruction manuals provide information on how to do so for specific engines. Improper injection can cause washing away of the lubricant from cylinder walls and rings, resulting in wear or scoring. Poor atomization or the use of fuel that is too heavy can cause ring sticking and contamination of the lube oil with soot.



*Courtesy of Caterpillar Tractor Company*

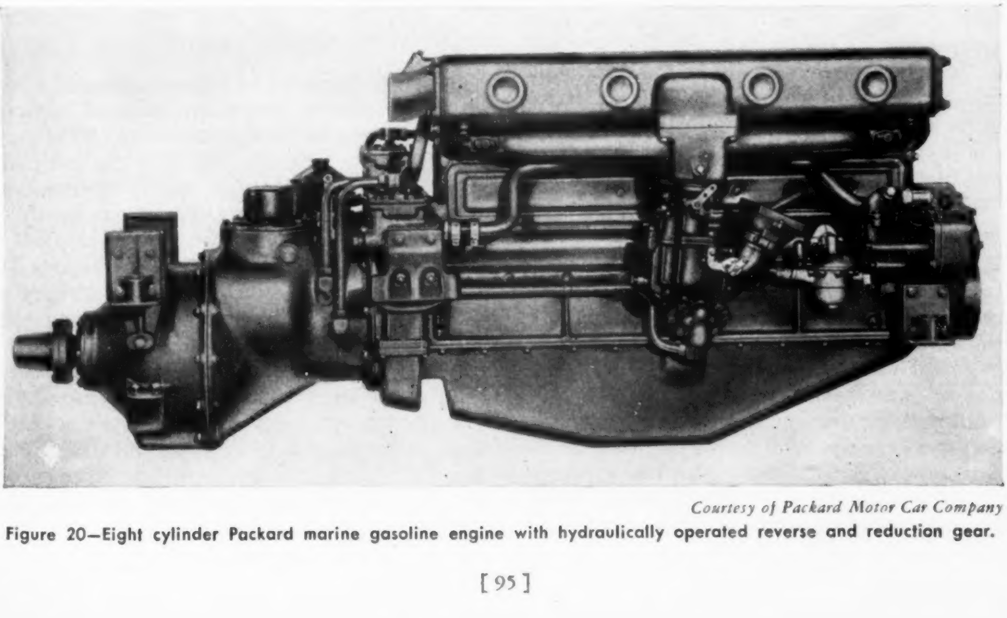
**Figure 19—Cross-section of Caterpillar D 17000 marine Diesel engine, showing lubrication system and Twin Disc gear.**

The maximum amount of fuel injected, and consequently the maximum power obtained from an engine, can be increased over the manufacturer's normal setting only at the expense of the engine life and possible undesirable exhaust smoke and odor.

## REVERSE AND REDUCTION GEARS

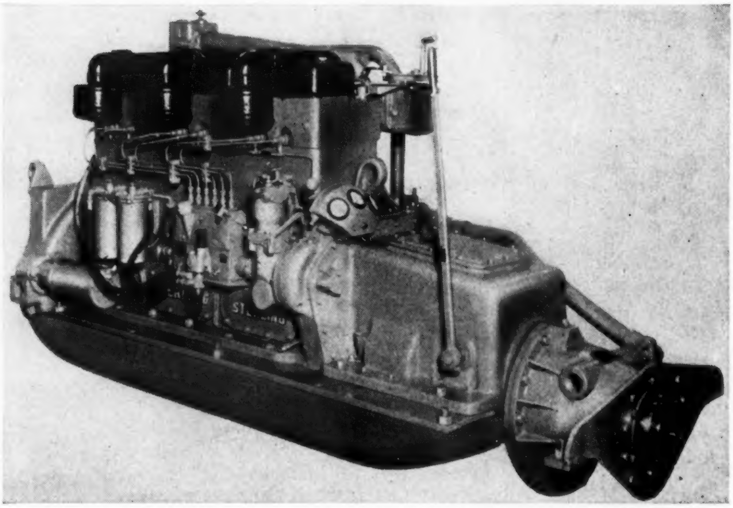
Many types of reverse and reduction gears are available, some of which are shown in the accompanying illustrations. The reverse gear is, of course, necessary in marine installations and is universally provided. The built-in type of reverse gear is most popular, using oil from the engine crankcase for lubrication.

Reduction gears are used to reduce engine speed to a more efficient and economical propeller speed. The efficient and economical use of power, in terms of miles per gallon of fuel, and smooth performance of motor boats are largely controlled by the



*Courtesy of Packard Motor Car Company*

**Figure 20—Eight cylinder Packard marine gasoline engine with hydraulically operated reverse and reduction gear.**



*Courtesy of Sterling Engine Company*

**Figure 21—Sterling "Viking" Model MRDB-8 marine Diesel engine.**

relation of propeller size and speed to the requirements of the boat hull. Power is wasted when either the size of the propeller or its rpm is out of proportion to the speed of the boat.

Straight-line, off-set, V-drive, and silent chain reductions have all been successfully used, with a predominance of the first two in number of installations. The advantages of the V-drive and silent chain reduction units is in location of the engine in the stern, thus making more space available in the center section of the boat and shifting the center of gravity aft for possible improved handling and thrust characteristics.

Lubrication of reduction gears may be accomplished by oil under pressure from the engine lubricating system, or, as is more common, from an independent oil system in the base of the gear case. The latter system is used even for many built-in reduction gears which, with the reverse mechanism, are furnished as an integral part of the gasoline or Diesel marine engine. Some of these gears use oil of the same viscosity and type as used in the engine, while others use straight mineral gear oils in the SAE 90, 140, or 250 viscosity ranges.

Gear oils of 140 Grade or SAE-50 engine oils are recommended for most reduction gears under summer conditions. As colder weather approaches, it is advisable to consider a reduction in the viscosity of the gear lubricant, say to SAE 90 Grade gear oil or to SAE 40 or 30 engine oil if operation is to continue. At the time of change, cleaning and flushing the gear case with motor flushing oil will remove abrasive foreign matter which might otherwise cause wear or scoring of gear teeth if allowed to accumulate and contaminate the gear lubricant.

## ENGINE ACCESSORIES

The lubrication of marine engine accessories largely follows automotive practice since the bearings and moving parts of accessories such as water pumps, starters, generators, distributors, and magnetos are largely similar. Marine generators and starters differ from those used for automotive service in that non-ventilated or closed construction is used to prevent entry of spray and moisture.

The lubrication requirements of water pumps, either of the plunger or various rotating types, are comparatively simple, provided adequate attention is given to the choice of a suitable lubricant. It is essential that a water pump grease be insoluble in water and of sufficient consistency, or body, to form an effective seal against leakage. The use of automatic grease cups or pressure cups assures positive lubrication as long as the cups are kept filled.

Bearings of electrical mechanisms such as generators and magnetos require a few drops of light oil at regular intervals, which should be a regular item on the maintenance schedule. Distributors may be oil lubricated, or may have compression type grease cups which require periodic additions of grease and adjustment from time to time as the lubricant is depleted. Aside from this, other parts are permanently lubricated with grease which requires renewal only when overhauling or repairing the mechanism.

## CONCLUSION

In the development of power boating as a sport and as an industry, petroleum fuels and lubricants have played a vital and prominent role. The petroleum industry, through its individual oil companies, has contributed to this development and to making boating pleasant through constantly improved products to match the advances made by boat and engine builders. Other contributions have been made through furnishing special services and instruction to boat owners, and through establishing service outlets and facilities on all waterways throughout the United States. These facilities will continue to contribute to the widespread growth and development of boating in its many forms. Also continuing will be research and development in the petroleum industry to provide boatmen with the petroleum products best suited for their safety and pleasure afloat.



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